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ELECTROHYDRAULIC EFFECT

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ELECTROHYDRAULIC EFFECT

This brochure gives a short description of the phenomena accompanying a high-voltage discharge in a liquid. This phenomenon (called the "electro-hydraulic effect" by the author) consists of the fact that, when a especially shaped electric pulse discharge is produced inside a liquid, extremely high pressures arise in the neighborhood of the discharge. These high pressures can be used extensively for practical purposes.

Because of the novelty of the question and the prospects of multiple applications of the results achieved, this brochure is of interest for a broad group of workers in different fields of specialization, both in the area of the physics of electric discharges, and in the area of utilization of high pressures and elastic impulses.

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PREFACE

When a especially shaped high-voltage electric pulse discharge is produced inside a liquid, extremely high pressures are formed in the area of the discharge. These high pressures manifest themselves in extremely different ways, as in mechanical destruction of objects in the neighborhood of the discharge, ejection of liquid, etc.

It has been possible to establish experimentally the existence of certain laws regarding the nature and results of this ~~pmk~~ phenomenon, which we have called the "electrohydraulic effect". The possibilities of using this phenomenon for practical purposes have been determined in a general form.

This brochure contains a short description of the electrohydraulic effect, the method of study, and the results of the experiments conducted, as well as discussions on its prospective use.

The rates of development and the practical exploitation of ~~[illegible]~~ electrohydraulic effect, which is now in the initial stage, will depend to a considerable extent on the active use of scientists, engineers, and technicians for the realization of this new method. The novelty and unusualness of the assumptions, facts and conclusions given in the brochure may give rise ~~[illegible]~~ a number of objections and doubts in individual readers. The author ~~xxx~~ has no desire to

defend individual formulations, as he is fully prepared to ~~suggest~~ admit the existance of inaccuracies in them, and will be grateful to his readers for objective theoretical criticism. In conclusion, the author regards it as his duty to express his deep gratitude to the organizations and persons who provided him with cooperation and help in the execution and publication of this work.

Author

Chapter I

Phenomena in a Liquid near the Zone of Discharge

1. Basic circuits.

Since 1938, the author has studied phenomena which arise in the neighborhood of a high-voltage spark discharge in a liquid medium.

In their initial stage, these studies confirm the existing data that, in liquids with ionic conductivity, either such discharges do not take place at all, or they take place only in cases where the spark gap is very small. In the latter case, the discharges are always accompanied by abundant formation of gas and vapor.

In dielectric liquids a discharge arises easily and is also accompanied by a considerable formation of gas and vapor.

The mechanical action of ~~a~~ the liquid on objects placed near the ~~tunnel~~ channel of the discharge produced in the circuit given in Fig. 1 is practically insignificant for liquids with ionic conductivity and is, relatively speaking, appreciable only in a liquid-dielectric medium.

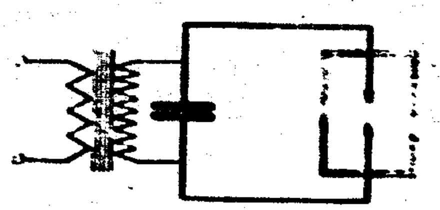

Fig. 1. Circuit of a set up for studying the break-down of liquids.

1- tank with liquid, 2- spark gap. The connections of the kenotron are not shown. The discharge circuit is indicated by the heavy line.

In both conducting and dielectric ~~[illegible]~~ liquids, the mechanical action is determined by the pressures inside the vapor-gas bubble formed in the discharge zone. According to the data in the literature, the values of these pressures are small.

The hydraulic pulses produced in the liquid in the examined cases have a sloping front and a long duration, and are not very powerful.

The author set himself the task of finding the conditions under which the action of hydraulic pulses could be greatly increased. It is obvious that the discharge ~~in~~ channel with the high pressures existing in it cannot be in direct contact with the liquid and send up the same pressures in it, but rather that it affects the liquid through a layer of gas and vapor. Consequently, to raise the pressure and increase the mechanical action of the liquid on objects, it ~~is~~ was necessary to find means of reducing the thickness of the envelope of gas and vapor and to reduce the duration of the discharge, during which it is established and is in existance. Simultaneously, it was necessary to increase the power of a single pulse. $\frac{5}{6}$

To achieve this, the ~~[illegible]~~ two simplest electric circuits were selected.

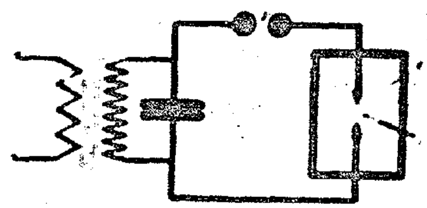

Fig. 2. Circuit of a set-up with an additional spark gap:

1 - tank with liquid; 2- main spark gap; 3- additional spark gap; (the connections of the kenotron are not shown).

The first circuit (Fig. 2), characterized by an additional spark gap, made it possible to obtain a spark gap in liquids with ionic conductivity, to greatly increase the mechanical effect, and to almost completely eliminate the formation of gas and vapor.

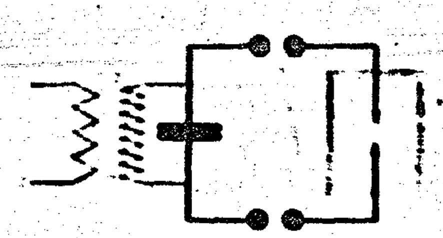

Fig. 3. Circuit of the basic set-up for reproducing the electrohydraulic effect with two additional spark gaps:
1- tank with liquid; 2- main spark gap; 3- additional spark ga p. (The connections of the kenotron are not shown).

The other circuit (Fig. 3), which was subsequently adopted as the basic circuit, contained two additional spark gaps (which we later called "shapers") connected in series on both sides of the main spark gap. It was established that, if the length of the shaping spark gaps and the main spark gap were chosen suitably, this circuit made it possible to increase still more the mechanical action of the discharge and to totally eliminate (at least to the eye) the formation of gas and vapor.

Experiments showed that a further increase in the number of gaps reduced the intensity of the electrohydraulic effect.

These relaxations circuits preserve and maintain any discharge frequency, which is set by changing the length of the shaping gap, with the length of the main gap left constant. 6/7

The form of the pulse wave in a discharge produced in one of the above circuits varies according to principles well-known in electric engineering.

Hydraulic pulses arising as a result of a discharge in a liquid consists of two shocks: the basic hydraulic one, and the second cavitational one.

The form of the basic hydraulic pulses (or "electrohydraulic shocks") is approximately analogous to the form of the current pulses.

The shorter the length, the steeper the front, and the higher the amplitude of the current pulse, the shorter and stronger the hydraulic pulse will be and the

greater its brisance. On the contrary, the longer the current pulse and the lower its amplitude, the greater the duration of the hydraulic pulse and the weaker its destructive action will be.

The introduction of the two additional, shaping spark gaps in the electric circuit gives it special properties, which are required for the establishment of the electrohydraulic effect.

The additional shaping gaps make it possible:

1) to accumulate measured amounts of energy, which are then pulse-fed to the main gap;

2) to reduce considerably the pulse duration, to prevent the arising of oscillating processes, and to obtain in effect one powerful, extremely short pulse in each cycle;

3) to establish a steep pulse front, eliminating the possibility of an arc discharge;

4) to obtain with a given main spark gap any of the values of the current and voltage permitted by the given power system;

5) to change the form of the pulse and the nature of the discharge in the main gap by symmetric or asymmetric adjustment of the length of the shaping gaps;

6) to establish a sequence in the break-down of the gaps in which first the supplementary shaping gaps and then the main gaps break down, the greatest portion of

the energy being given off at the main gap.

These and other advantages of the circuitg, in addition to its simplicity, were factors in its selection. However this provides no basis for regarding it as the only suitable circuit for producing the electrohydraulic effect.

When the installations are adjusted through supplementary shaping gaps, they operate stably over a broad range. When the shaping gaps are closed, the liquid between the points of the main gaps passes the current freely.

If the shaping gaps are gradually opened up, break-downs will begin to occur in them, although no break-down will arise in the main gap at first. The reason for this is that the voltage across the main gap falls so rapidly that the voltage and pulse shape are in position for a break-down.

The lower limit of stable operation is given by the length of the shaping gaps at which they both shape the pulses suitably and provide the voltage sufficient for break-down of the main gap. The upper limit of stable operation occurs at the point where, when the gaps are further enlarged, the voltage produced by the power unit is no longer sufficient for all three gaps (the two shaping gaps and the main gap) to break down.

Thus, it is possible to regulate broadly the voltage, the power, and the shape of the pulse wave fed to the main gap.

§ 2. Distinctive Features of the Electrohydraulic Effect

It should be noted that the electrohydraulic effect differs essentially from electric spark treatment of metals. This difference lies not only in the completely different electrical circuits, physical processes, and energy parameters, but also in the fact that, in the electrohydraulic effect, the discharge does not have a direct mechanical action on an object, but an indirect one, acting through the medium in which the spark arises.

In electric-~~spark-processing~~ arc treatment of metals, the so-to-say linear (in the direction of the discharge) thermal action of pulse discharges is used, the voltages and durations being considerably smaller.

On the contrary, the electrohydraulic method is based on the radial (perpendicular to the direction of the discharge) mechanical action of the expanding channel of a high-voltage and extremely short ~~pulse~~ pulse-type discharge on the surrounding liquid medium, which transmits this action to the object under treatment.

Thus, in the electrohydraulic effect, there is no thermal action on the object, while the mechanical action takes place through a liquid medium, without direct electric contact.

As a development of the wide-spread views ~~of~~ regarding the thermal nature of the process of electric-~~spark-processing~~ arc treatment, the author believes, on the basis of his experiments,

that the metal melted by a current pulse is most likely ejected by the forces of the thermal outburst and by the subsequent cavitation, rather than by electrodynamic forces.

Any liquid can be used as the medium in which the electrohydraulic effect is produced. The most convenient liquid is industrial water. The less compressible the liquid, the higher the resulting pressure and the greater the brisance of the electrohydraulic pulses will be.

The liquid medium surrounding the discharge channel receives the high pressures formed in it and transmits them to some extent to the nearest object.

The smaller the number of layers separating the liquid medium from the discharge channel and the smaller the total thickness of these layers, the more rapidly the pressures will be transmitted and the higher their amplitude will be.

The denser and less compressible the liquid surrounding the discharge channel, the closer the pressures formed in the liquid will be to the pressures in the spark channel.

Since a liquid medium can be regarded as practically incompressible (for water, for instance, the coefficient of compression is 0.000048), this explains the enormous mechanical stresses in electrohydraulic devices.

Ordinary technical methods make it possible to change the duration of the pulse

discharge and its nature as desired. Correspondingly, the nature of the pressure formed in the liquid can be of any sort. This makes it possible to use the electrohydraulic effect for different purposes.

3. Manifestations of the Electrohydraulic Effect.

The electrohydraulic effect can be easily observed in an open vessel filled with any liquid.

At the same time, it is possible to see the importance of preliminary shaping of the pulse.

For instance, if a powerful, but not specially shaped pulse breaks down ~~the~~ a layer of liquid of 100 - 150 mm without producing any important external mechanical effects (only a slight oscillation of the surface of the liquid is observed).

At the same time, a less powerful, but specially shaped pulse ejects up to 10 - 15 l of liquid to a height of several meters with the same spark ~~time~~ length, or else ~~this~~ it can destroy a strong vessel with a volume of about 400 l made of ~~organic glass~~ Pyrex 16 mm thick and fastened with bolts.

The acoustic effect of an electrohydraulic shock also exceeds ~~the effect~~ that of discharges with the same power, ~~within~~ but without a special shape.

Thus, the electrohydraulic effect represents a <u>fundamentally new way of transforming electric energy into mechanical energy</u> without any intermediate links, with a high conversion factor suitable for industrial utilization.

It is well known[1] that the break-down voltage in liquids does not depend on pressure, asymptotically approaching the same limit in almost all liquids at a few thousand atmospheres.

On this basis, it can be supposed that in working at these pressures, the efficiency of electrohydraulic devices may be very high. This also explains the high production of energy in an electrohydraulic impulse at atmospheric pressure. 9/10

The liquid surrounding the discharge zone has an enormous resistance to the expansion of this zone.

Since the discharge channel has a negligibly small cross-section in the initial stage of the process, the increase of the energy density in it and of its cross-section takes place extremely rapidly, as a result of which the phenomenon is of the nature of an explosion.

Thus the resistance to the expansion ~~in~~ of the discharge channel is a special type of resistance to current, but in contrast to ordinary resistances it is directed in a radially perpendicular direction to the current, rather than in a linearly opposite direction.

This resistance is extremely large - thousands of joules are given ~~up~~ off in a microsecond. Therefore the circuit capacitance across the main spark gap will not

1) Bridgeman, Fizika Vysokikh Davlenii, Per. S. Angl. (High Pressure Physics, Trans. from English.) GTTI, 1949.

operate as though it were short-circuited at the moment of break down.

In the initial stage of expansion of the channel, the spark discharge which developes without being sustained takes place inside an extremely dense "tube" of liquid, which has a great resistance to the further expansion of the discharge. This phenomenon takes place at pressures considerably exceeding the above-mentioned critical pressures, and thus both the conversion coefficients and the output of useful energy are extremely large.

When discharges are obtained in water and other ion-conducting liquids, according to our basic circuit, these liquids behave as insulators. Ordinary insulators placed in these liquids not only do not lose their insulating properties, but even seem to improve them.

The high electric strength of ion-conducting liquids in the electrohydraulic effect is connected with the exceptional speed of the break-down. Here the small mobility of the ions in the liquid manifests itself in the fact that they obviously cannot move from their positions during the process.

This In experiments it was noticed that an increase of the concentration of certain ions in liquids which previously did not conduct current suddenly gave them a high conductivity, comparable with that of metals.

It was remarked, that, as the steepness of the wave front increased, and

the length of the wave decreased, the pulses' ability to break down a concentrated solution of any electrolyte increased appreciably. Obviously, with any concentration of electrolyte, it is possible to have a breakdown in the solution by using a pulse with a very steep wave front and an extremely short wave length.

During the investiations, it was established that a high-pressure zone with a characteristic shape (fig. 4) arises above the discharge channel when a breakdown is produced in a liquid by means of the basic circuit. For illustrative purposes, we divide this zone into a number of parts.

A- zone of the spark discharge.

B- disintegration zone. Almost all materials disintegrate into dispersed particles, while the liquid in this zone seemsto acquire the properties of a brittle solid body[1].

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1) According to M. Kornfel'd, (see his book "Uprugost' i prochnost'" /Elasticity and Strength of Liquids/, GTTI, 1951), the modulus of displacement of a liquid is definitely less than the previously proposed value of 10^{10} dynes/cm^2, while the relaxation time of the liquid is much greater than the previously assumed value of 10^{-10} - 10^{-12} sec.

Consequently the hypotheses that a liquid may acquire the properties of a solid body in the zones nearest the discharge zone are probably correct.

Kornfel'd asserts that "liquids will behave as solid bodies at reaction periods much greater than the above mentioned relaxation time..." (see 71).

C- cold-hardening zone. Many materials disintegrate, metals are cold-hardened and the liquid is apparently in the state of a solid elastic body.

D- Zone of elastic action. Particles are ejected, powerful ejecting forces arise, and the liquid is apparently in the state of a very elastic liquid body.

E- Compression zone. The pressure decreases very rapidly with increasing distance from the origin. Large volumes of liquid change position.

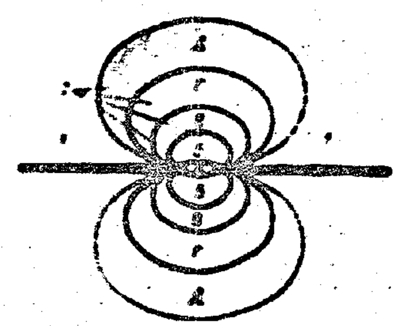

Fig. 4. Diagram of the shape and sequence of pressure zones about the spark discharge in the initial period.

1- electrodes; 2- pressure zones.

Metals cannot be placed in the disintegration zone (B) at distances less than half the spark length, since a break-down to the metal arises (short-circuiting through the metal).

Similarly, a metal object used as one of the electrodes cannot be placed in the disintegration zone.

It can be seen from Fig. 4 that a conducting object used as an electrode is subject to the influence of only the edge pressures of the cold-hardening zone (C). This produces a shallow cup-shaped hollow on the electrode at the point where the spark strikes.

It follows from Fig. 4, that when the end of the electrodes are placed in a straight line, practically no mechanical forces act on them. Only in the case of very thick electrodes are the points smoothed by the action of streams of liquid.

The diameter of the disintegration zone is proportional to the pulse power. For instance, in a set-up with an electrophorus and an induction coil, with a capacitance C = 0.05 μf and a spark length in the liquid of 8 mm, the diameter of the disintegration zone is equal to 2 - 3 mm. Table 1 shows the diameter of the disintegration zone when the power source is a 100-kv d-c X-ray transformer connected through a KR-110 kenotron. 11/12

The zones B, C, D, E which surround the disintegration zone have correspondingly large dimensions.

The instantaneous power of individual pulses is extremely large. For instance, in a set-up with a power of one kw at 50 - 70 kv, the power in a single pulse attains more than 100,000 kw.

Table 1

Diameter of the disintegration zone on standard abrasive wheels.

Experiment No.	Voltage, kv	Capacitance, μf	Spark length, mm	Diameter of the disintegration zone mm
1	30	0.2	10	5
2	30	0.7	10	7
3	30	0.7	30	1
4	50	0.7	50	26
5	50	0.7	70	38
6	50	0.7	90	45
7	50	0.7	110	57
8	70	0.7	130	69
9	70	0.7	150	75
10	70	0.7	170	82
11	70	0.7	190	95
12	70	0.7	210	105

The erosion of the electrodes is not very appreciable and can be observed only at large capacitances and with a small length of the main spark gap. However, in all cases, it is possible to select circuit parameters such that the erosion of the electrodes of the main spark gap will be practically nonexistent. This is extremely important in the production of the effect.

The experiment showed that the discharge forms and takes place more easily with iron electrodes than with copper electrodes. This shows the influence of the electrode material on the breakdown process.

The investigation also showed that, in the case of a "point-to-point" discharge in water, there is almost no branching, but that, in the case of a "point-to-disk" discharge, branching frequently appears at the end of the discharge and can be seen

from the slight erosion at the places where the branches of the discharge enter the surface of the disc. In some discharges, up to 5 - 8 branches with different 12/13 cross-sections could be observed, as could be easily established from the different areas of the points of erosion.

Both branching and non-branching discharges give the same results.

The electrohydraulic effect is not accompanied by the formation of gas and vapor. For the case of work in water, it can be assumed that the minute amounts of gas and vapor which could be formed during the exceedingly brief discharge either will be "burned up" by this same discharge at the end of its existence, or will immediately condense and dissolve in the liquid when the discharge is completed.

The process of a break-down in the main spark gap obviously differs from the cases of a conducting medium and a non-conducting medium.

Before the break-down, water in the main spark gap behaves like a conductor and therefore provides a potential of the same magnitude in the entire right part of the circuit (Fig. 3) beyond the shaping spark gap.

When one of the shaping spark gaps breaks down, the water instantaneously ceases to be a conductor, practically becoming an insulator. At the same time a streamer with a definite polarity (hence - the type of break-down) begins to form in the main spark gap from one electrode to another.

When the streamer attains a certain limit, the second spark gap breaks down and the streamer short-circuits the two electrodes, i.e., the mains spark gap begins to brea kdown. At this moment, all the energy accumulated in the circuit is collected in the right part of the circuit, i.e., ~~at~~ practically all of it goes to the main spark gap.

Then the spark channel expands to the limit determined by the powers of the current. After this, the cavity accompanying the main shock forms, and it is filled with liquid, completing the cavitation shock.

If the liquid is a dielectric, it is always a worse insulator before the break down of the shaping spark gap and a better insulator after the break down. Until one of the shaping spark gaps breaks down the potential in the right part of the circuit will not be the same, and the spheres of the discharges will be at different potentials.

It also appears that the second spark gap breaks down before the streamer reaches the second electrode.

Experiments have shown that less energy is given off in the main spark gap in dielectric liquids than in water. This cannot be explained simply by the greater density of water.

The discharge channel expands with enormous velocities, slowing down towards the end of the process. In the beginning of this period of direct contact with the

liquid, transmission of heat and of the pressure of the liquid takes place through the thin envelope of vapor and gas surrounding the spark zone. Then the velocity of the liquid scattering from the spark zone catches up with the expansion of the 13/14
discharge channel, and the liquid moves apart to the limit given by some equilibrium, forming a cavity.

In the limiting expansion of the cavity, its walls are obviously under a pressure permitting the existance of the cavitation bubble, with consideration taken of a certain amount of gas and vapor inside the cavity.

The gases and vapor then expand, cool off, the cavity closes, the gas and vapor condense and dissolved, and with this the entire cycle is completed.

The heat given off in the main gas is negligibly small, and the electrodes and objects under treatment are not heated up.

However, in very small volumes of liquids, if the capacitances are extremely large and the main gap is extremely small, the amount of heat given off (at a high discharge frequency) becomes more appreciable.

As we have already pointed out, the electrohydraulic effect is accompanied by cavitational phenomena.

On the path of the discharge, the continuity of the liquid is broken, the

molecular cohesion of the particles being overcome, and a cavity is formed.

Immediately after the discharge has ceased, the walls of the cavity close. This takes place with sonic or supersonic velocities. This process is accompanied with the same phenomenon as the well-studied process of cavitation.

The size of the hollow cavities formed in electrohydraulic shocks in liquids may be quite large.

Thus, with a spark length of 45 mm, a capacitance C = 0.7 f, and a voltage of 50 kv, the cavity was spindle shaped, having a length of 80 mm, with a greatest diameter of 70 mm and a volume exceeding 100 cm^3.

When these cavities are formed, they are filled with traces of the products of gas and vapor formation, which is unavoidable in powerful discharges.

The insignificant amount of gas and vapor formed about the discharge zone expand and fill the entire cavity. In this process, they cool down greatly and condense.

Closing in of the walls of the cavity produces the cavitation shock, which supplements the main shock of the discharge.

If the discharge takes place near the surface of some object, the cavity is deformed and has a single-ended hemispherical shape. The single-ended filling of the cavity with liquid produces a cavitational shock on the surface of the object.

This results in more or less intense disintegration of the surface.

The formation and subsequent filling of the cavity also confirms the existence of extremely high pressures in the discharge zone. Experiments make it possible to regard the pressures obtained as proportional to the power of the pulse and inversely 14/15 proportional to its duration, and as depending on the coefficient of volume compression of the liquid/

From the nature of the damage of various materials in the disintegration zone, it is likewise possible to conclude that the pressure must be extremely large.

The amount of liquid necessary for the electrohydraulic effect is extremely small. Thus, the thickness of the layer of water between two plates of glass placed on top of one another is a few hundreds of a milimeter, yet this is sufficient for the glass to be broken by the electrohydraulic shock from the discharge of an electrophorus, even though there is no such effect in air after hundreds of electrohydraulic shocks.

This set-up can also be used to note the absence of gas and vapor: with sufficiently thick plates of glass, capable of withstanding several shocks, no gas bubbles can be seen in the water between the glass plates.

The pressure formed by a single pulse depends, within certain limits, on the capacitance.

On the one hand, an increase in the capacitance raises the pulse duration (i.e., "softens it"), reducing the magnitude of the pressure, but, on the other hand, this same factor increases the amount of energy given off in the spark channel, and consequently increases the dimensions of the above-mentioned zones and raises the pressure in them.

The circuit used by us can be adjusted to various frequencies of succession of the pulses, which then remain ~~very~~ fairly constant.

In working with a-c current, it is possible to regulate the circuit to have the breakdown take place at the maximum amplitude of the voltage with the frequency of the supply current.

However, the decisive role in obtaining the required results is played by the steepness of the front of the pulse obtained.

To increase the steepness of the front and shorten the wavelength of the pulse, it is possible to use well-known methods, including firing the spark gaps. Study shows that the rigidity of the pulse is greatly increased by the use of firing.

In one of the experiments, conducted in 1951, a pulse generator producing a voltage up to 500 kv was used as the power unit.

It was assumed that this generator would produce a considerably stronger effect

than the previously used sources. However, when the experiment was carried out without supplementary shaping spark gaps and without a special capacitance in the circuit, the electrohydraulic effect was totally absent, despite the existence of a discharge 80 mm long in the water.

After one shaping spark gap with spheres 50 mm in diameter was conducted, there was a small pertubation on the surface of the liquid. The discharge had a length of about 80 mm, the shaping spark gap a length of 30 mm, the voltage amounted to 200 kv and the depth of submersion was 200 mm.

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After a second spark gap with spheres 30 mm in diameter had been installed with the same circuit parameters and with supplementary spark gaps of 20 and 30 mm, an ejection of up to 250 cm^3 of liquid to an average height of one-half a meter was recorded.

These experiments showed the great importance of this steepness of the pulse front in the production of the electrohydraulic effect, as well as the need for the special discharge circuits.

Pulses from a pulse generator which were fairly steep in discharges in air were less steep in discharges in water.

The inclusion of shaping spark gaps increased the steepness, but the electrohydraulic effect did not reach maximum strength, despite the great power of the set-up.

However the discharge circuit was not completed yet, and to obtain the maximum electrohydraulic effect it was necessary to connect a separate capacitance. We called ~~Suppose~~ the discharges of the first type, which, though powerful, did not produce an electrohydraulic effect, "soft" discharges. These dischargeshave a sloping front, a large wavelength and a small pulse power.

In a very rare instances, approximately one out of a thousand cases, we observed the appearance of soft discharges when a normal circuit with supplementary spark gaps and a capacitance were used. These discharges were accompanied by a very weak acoustic ~~sound~~ effect, and a practically negligible electrohydraulic effect.

Subsequently it was established that in a normal circuit the soft discharges arose only when the equipment was adjusted to the minimum breakdown voltage and the lengthsof the shaping spark gaps differed greatly from one another.

After the circuit had been adjusted to stable operation of the main spark gap, no more soft discharges were observed in it.

A further increase in the steepness of the wave front and a reduction of the wavelength will apparently make it possible to have a disruptive breakdown in metals.

This was ~~[illegible]~~ confirmed by an experiment in which we produced a breakdown in mercury by using our circuit and an electrophorus ~~electrofasee~~ to supply it.

Chapter II

EXPERIMENTAL DATA

4. Equipment and instruments for the experiments.

To conduct the experiments ~~xxxxx~~ described in this brochure, four types of power sources were used:

1) a school type electrophorus with U = 50 kv and W = 3w;

2) aschool type induction coil with U = 50 kv and W = 30w;

3) a laboratory induction coil with U = 30 kv and W = 500 W;

4) an X-ray transformer with U - 100 kv and W = 3 kw.

The greater part of the work was conducted with this last power source, connected ~~xxx~~ into a half-wave rectifier with a KR-110 kenotron. Thus, only half of the power of the transformer was used; i.e., 1.5 kw instead of 3 kw.

The capacitances used in the experiments with this transformer made it possible to have 0.03, 0.2, 0.5, 0.7, and 1.0 μf in the circuit.

The maximum length of the discharge in water depends appreciably on the capacitance of the circuit. Thus, even at 50 - 80 kv it was impossible to obtain a ~~xx~~ spark longer than 5 mm with a capacitance of 0.3 μf, while at the same voltage sparks 100, 150, and even 200 mm long were easily formed with a capacitance of 0.7 μf. With a capacitance of 1 μf and a voltage of 80 - 100 kv, it was possible to obtain sparks up to 220 - 250 mm long in water.

We also studied the attenuation of the pulses and the reduction of the steepness of their wave front when they were transmitted through fairly long cables (the effect of this is analogous to the existence of an additional distributed capacitance in the discharge circuit). Because of the difficulty of producing a distributed capacitance ~~in~~ with a wide range, it was replaced by a concentrated capacitance connected in parallel to the main spark gap, after the shaping spark gap.

In the study, it was established that a lumped capacitance ~~a~~ up to 0.05 μf does not reduce the strength of the electrohydraulic pulses.

No capacitances greater than 0.05 μf were connected.

The shaping spark gap made of nickel-plated spheres 50 mm in diameter could be adjusted to a wide ~~length~~ range of lengths during the operation of the set-up.

The experiments established that the erosion wear of the surface of the spheres of the shaping spark gaps is insignificant. Tens of thousands of discharges arising in these gaps damaged only the thin layer of nickel plate and caused an insignificant total erosion no more than 0.05 mm deep. The area of the erosion damage was confined to a spot 5 - 6 cm^2 large.

The discharges were produced in an open bath made of ~~organic glass~~ Pyrex 16 mm thick, fastened together with ~~gaskets~~ glue and bolts.

The tank was filled with tap water.

The transparent walls made it possible to observe and photograph the phenomena in the tank.

For the discharging studies, there was a special device on the bottom of the tank which made it possible to regulate the length of the main spark gap, change the material of the electrodes, to place them in any position ~~near~~ in the vicinity of the specimens under study, and so on.

With reference to the conditions of the experiments with a power source of 1.5 kw, we must add that the ~~organic-glass~~ pyrex bath had a large shortcoming, in spite of its convenience, since it broke at relatively unpowerful discharges.

As a rule, a discharge 80 - 100 mm long cause breaks and leaks in the tank, not to speak of the more powerful discharges obtained with this apparatus.

If the discharge was produced near the surface of the liquid by placing the spark gap of the discharge system at a depth less than 100 - 150 mm, the bottom of the tank was protected from being knocked ~~down~~ out, ~~since~~ but a large amount of water was ejected. Attempts to close the tank with a cover did not improve the situation, since both the cover and the weight placed on it were lifted and thrown aside.

Whatever the type of protection of the tank, discharges longer than 150 mm could be conducted only ~~under~~ on the condition that the ~~tank would~~ tank be damaged.

For this reason, we have no photograph of discharges longer than ~~10~~ 135 mm, although we produced several such discharges

5. Nature of the Discharges Studied and their Action

With the above-mentioned apparatus, we carried out a number of discharges, the conditions of productio n of which are given in Table 2. Some of the photographs are shown in figures 5 and 6.

In a number of cases, when the discharge gap was not submerged to a sufficient depth, it was noticed that the breakdown did not take place between the electrodes, but that it was directed vertically upwards from one of the electrodes 18/19 and propagated along the surface of the water, travelling more than 300 mm to the conductor of the second electrode. In individual experiments, charges sliding along the surface of the liquid travelled up to 500 mm and more.

Table 2.

Conditions of Formation of the Discharges

Fig. No	Voltage, kv	Capacitance μF	Spark length mm	Arrangement of the electrodes	Shaping gaps left (+) mm	Shaping gaps right (-) mm	Depth of immersion in mm	Notes
				Linear				Single discharge
								ditto
								Two discharges in sequence
								Single discharge
								ditto
								Discharge sliding on the surface
								Sliding discharge
								Ditto
				According to fig. 8				50 mm in air, 50 mm along the surface, and 50 mm in water
				According to fig. 9				25 mm in water 55 mm along the surface, and 25 mm water

SEE NEXT PAGE

Conditions of Formation of the Discharges

1	2	3	4	5	6		7	8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
					[illegible] (+)	[illegible] (-)		
[illegible]	20	0,2	10	Линейное 11	10	10	[illegible]	[illegible] 12
[illegible]	[illegible]	0,7	10	"	10	10	[illegible]	То же 13
—	40	0,7	[illegible]	"	15	15	[illegible]	"
	40	0,7	[illegible]	"	10	10	[illegible]	[illegible] 14
—	70	0,7	[illegible]	"	15	20	[illegible]	[illegible] 12
	70	0,7	[illegible]	"	12	18	[illegible]	То же 13
	[illegible]	0,7	[illegible]	"	10	[illegible]	[illegible]	[illegible] 15
7	50	0,01	100	"	10	[illegible]	"	[illegible] 16
—	50	0,01	100	20	10	10	"	То же 17
[illegible]	[illegible]	0,7	[illegible]	по фиг. 8 21	10	[illegible]	[illegible]	[illegible] 18
11	[illegible]	0,7	[illegible]	по фиг. 10	10	10	"	[illegible] 19

1) Fig. No.; 2) Voltage, Kv; 3) Capacitance mF; 4) Spark length, mm; 5) Arrangement of electrodes; 6) Shaping gaps; 7) Depth of immersion in mm; 8) Notes; 9) Left (+) mm; 10) Right (-) mm; 11) Linear; 12) Single discharge; 13) Ditto; 14) Two discharges in sequence; 15) Discharge sliding on the surface 16) Sliding discharge; 17) Ditto; 18) 50 mm in air, 50 mm along the surface, and 50 mm in water; 19) 25 mm in water, 55 mm along the surface, and 25 mm in water 20) According to Fig. 8; 21) According to Fig. 9.

Sliding discharges, which are obtained when the power source is an electrophorus has a special nature.

It can be seen from the photographs ~~that~~ (Fig. 7) that in the direction of the discharge path from the positive pole of the instrument there are no curves. The directions of the paths of discharge change at definite angles (~~see~~ 2 Fig. 7). Rotations of the sparks can be observed - immediately after a change in direction, the sparks seemed to be turned on edge (they are narrower), and then, after a new change of direction, the are straightened out and seem to lie on their flat side. A curious phenomenon on the photograph is a spherical luminous formation (1, fig. 7), which seem to be covered x "antennae" and whose diameter attains 5-6 mm.

Despite the agitation of the liquid, the ~~frequent~~ place of formation of these ~~sgs~~ sparks remains constant from discharge to discharge, while their position coincides with inhomogeneities in the second electrode which lies in the bottom of the tank. 19/20

From the side, these spherical formations sometimes have a slightly conical shape, and the "antennae" of the individual spheres are frequently ~~would~~ wound in a spiral.

The spherical discharges are not connected with the zones of the linear discharges which occur concurrently. The nature and sequence of their formation

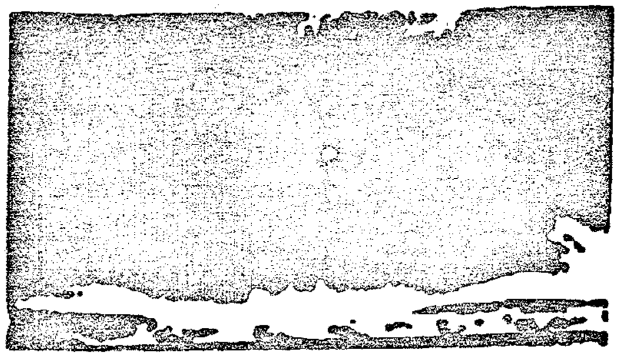

Fig. 5. Picture of the discharge 10 mm long in water, taken through the transparent wall of the tank. In this photograph and the next photograph, the (+) electrode is on the left and the (-) electrode is on the right.

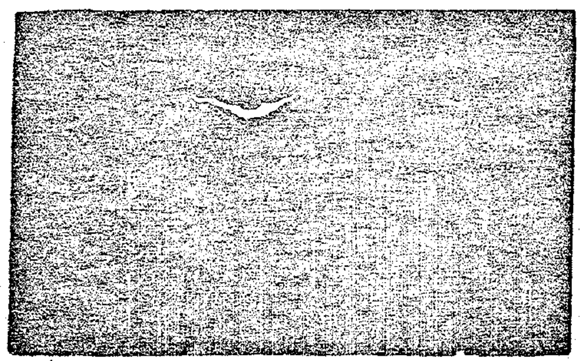

Fig. 6. A discharge 100 mm in length in water.

is determined by the size of the shaping spark gap, and in the given case, [illegible] indicate their non-simultaneous breakdown. The discharges from the negative pole, rectilinear at the beginning of their path, are deflected to the left and right with the same degree of curvature towards the end of their path. These deflections

embrace up to 3/4 of a circle, which appears to be part of a spiral. 20/21

The basic power source made it possible to produce a ~~xxxx~~ whole series of special discharges, the set-ups and photographs of which are given in ~~at~~ Figs. 8, 9, 10 and 11.

An unusual type of discharge was observed in one of the experiments, in which the positive electrodes had the shape of a point, while the ~~xxx~~ negative electrode had the shape of a disc. When the disc was set up from the point at a distance which was known to exceed the breakdown distance, it was possible to observe powerful "brush" discharges emerging from the point at each pulse. Each brush consisted of 5 - 10 pale-violet "antennae" up to 100 - 150 mm long and up to 8 - 10 mm thick. The "antennae" of the brushes oscillated very slowly, twisting about their central position. At their end, there were a small number of small (1 - 2 mm) gas bubbles. When the discharge stopped, they floated up, partially vanishing on the way.

The brushes were contained within a cone having the disc as ~~at~~ the base and the point of the second electrode as ~~at~~ the summit ~~summit~~.

We produced similar brush discharges in many electrolytic solutions, as well 21/23 as in polymerized ~~[illegible]~~ liquids. The discharge was accompanied either by coloring of the zone or by the appearance of precipitates (including even the formation of gelatinous colloidal formations as a result of the pulses).

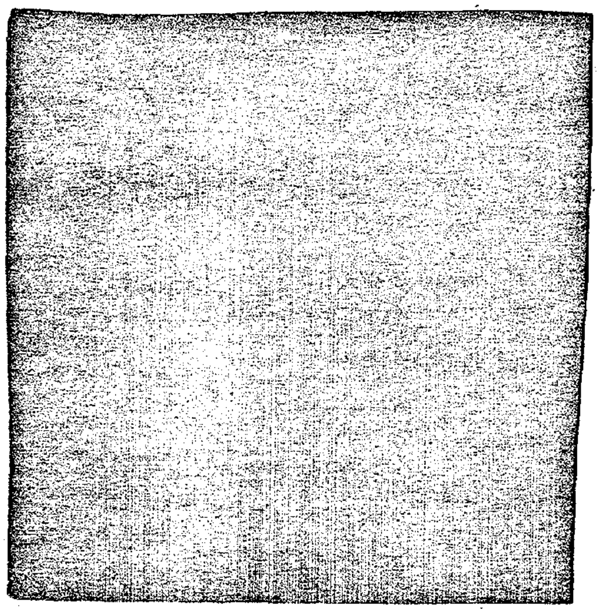

Fig. 7. Sliding discharges from the positive electrodes of an electrophorus having a path length up to 100 - 120 mm.

22

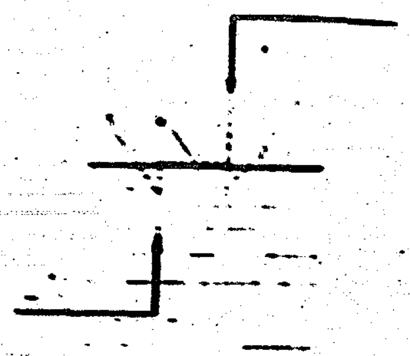

Fig. 8. Diagram of the discharge for the case where one of the electrodes (-) is in water while the other (+) is above the surface.

The discharge travels 50 mm in air, 50 mm along the surface, and 50 mm into the water to the second electrode.

1- electrode; 2- water; 3- path of the discharge of air; 4- path of the discharge along the surface of water; 5-path of discharge in water.

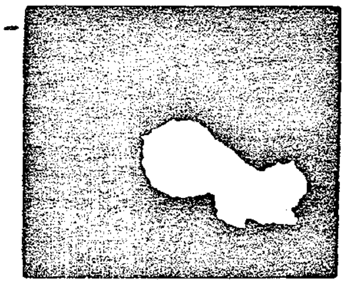

Fig. 9. View from above of a discharge taking place according to the scheme in Fig. 8.

22

On the right - path in air; on the left - path in water; in between - path along the surface of the water.

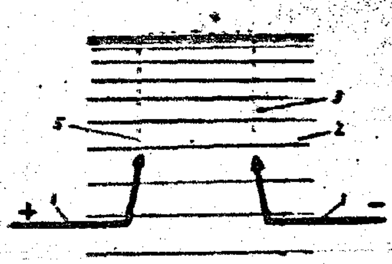

Fig. 10. Diagram of the discharge travelling 25 mm in water, then 55 mm along its surface, and finally another 25 mm into the water to the second electrode.

1- electrodes; ~~2mm~~ 2- water; 3- and 5- path of the discharge in water; 4- path of the discharge along the surface of the water.

The distance between the end of the electrodes in the water is 55 mm in a straight ~~in~~ line.

The unusual types of discharge include the electrodless discharge along the surface of a liquid obtained with the same set-up as in Fig. 10, but with the electrodes submerged somewhat deeper than they should be for the formation of a breakdown. When discharges took place in the shaping spark gap, brush discharges appeared on the surface of the liquid. These brush discharges were directed to the ends of the electrodes beneath the water and originated from a point lying on the surface of the liquid between the electrodes. They had the shape of two narrow "brooms" of pale-violet color, connected at their base. Depending on the voltage, their length attained 50 - 80 mm.

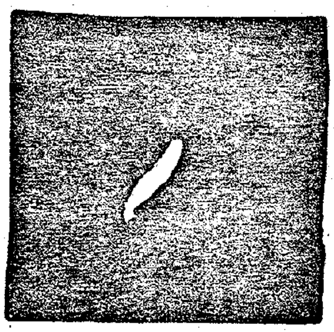

Fig. 11. View from above of the discharge taking place according to the set-up of Fig. 10.

The mechanical action of the electrohydraulic pulses, which manifested itself in all cases, was tested on the most diverse materials in various ways. In one of the experiments, the electrodes were fitted with textolite cones thick wire compressed with a

weak spring, between which a short metal tube was set up, ~~being~~ centered relative to the electrodes. Inside the tube, the ends of the electrodes were adjusted to a distance less than the tube diameter, to prevent a breakdown from taking place by way of the ~~xx~~ walls of the tube. The tube and electrodes were then emersed in liquids and pulses were fed to the electrodes. After one or two pulses, a bulge appeared in the tube. This bulge increased with each pulse. After 5 or 6 pulses, the tube usually ~~has~~ burst along the generatrix. With annealed tubes, it was possible to produce 10 to 15 electrohydraulic pulses. In this case, a large swelling was produced without damaging the tubes. 23/24

Fig. 12 shows samples of swollen brass tubes with a length of 100 mm, a diameter of 25 mm, and a wall thickness of 2 mm. After swelling, the tubes became noticeably shorter. Because of imperfections in the apparatus, the swelling accompanying each pulse often occurred in a different place from the others, as can be seen from the photographs.

The rupture in one of the tubes shown in Fig. ~~xx~~ 12 took place when liquid pierced a gas bubble held at the bulge in the tube, even though the swelling was made in an inclined position.

The appearance of ruptures ~~at~~ at the place of the gas bubbles presents an interest. In the described experiments, they were formed when the main spark gap was short and

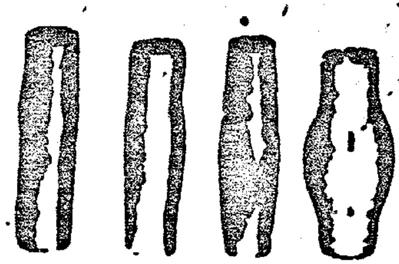

Fig. 12. External appearance of swollen brass tubes

1- after two shocks in different places; 2- after 3 shocks in different places; 3- rupture of the tube after 4 stable shocks; 4- swelling of the tube after 9 stable shocks with annealing of the tube after every third shock; 5- local bulge and rupture on the tube from the piercing of an air bubble.

the capacitance large. In other cases, no bubbles were observed.

The number of pulses necessary to swell the tube is proporational to the thickness of its walls. The greatest swelling and the amount of swelling depends on the properties of the tube material. These facts, which were established experimentally, will play an important role in the work of apparatus using the electrohydraulic effect.

This must be taken into account in ~~the~~ their design.

In forming a discharge from an electrophorus in a thin layer of liquid between two sheets of glass, placed tightly against one another, and having a size of 150 x 150 mm and a ~~thank~~ thickness of 5-7 mm, we observed that the electrohydraulic shocks were not able to overcome the force holding the glass sheets together. The sheets of glass did not move, but a piece of glass was knocked out from each of them on opposite sides. These pieces of glass reproduced ~~first~~ fairly accurately the appearance and shape of one of the zones shown in ~~a~~ Fig. 4. The diameter of each of these pieces was 40 - 50 mm. The remaining parts of the glass sheets remained intact, without any cracks.

If a spark discharge had to break through a piece of paper or cardboard on its path through the water, it was possible to observe, on the sheet of paper or cardboard, holes with smooth edges which were always cambered in the same direction - towards the negative electrodes.

When a discharge was produced from an electrophorus through air and a layer of kerosene poured on top of ~~the~~ a layer of water, which ~~has been~~ had been saturated with salts of some kind, and which conducted current <u>without</u> the formation of a discharge, a jet of gas flew out from the "hole" made in the layer of kerosene. This jet had a bluish green color and often ignited ~~itself~~ spontaneously (apparently from the same spark), 24/25

after which it burned with a sharp clap. With a 30-mm layer of air, a 15-mm layer of kerosene, C = 0.3μf, and shaping spark gaps of 5 and 15 mm, the jet was up to 1/2 meter long and was about 80 - 100 mm across its greatest cross-section.

Experiments with a power source producing 1.5 kw showed that, when a metal element with a large surface was electrically connected to the positive electrode of ~~the~~ a discharger, made in the form of a point, no discharge arose between the electrode ~~and~~ at any of the values of the current and the capacitance permissable in the experiment.

If the same metallic surface was connected to the negative electrode, it did not effect the formation and course of the discharges between the electrodes.

This observation opens up the possibility of rectifying pulses alternating in direction by means of a simple device. This device would consist of a discharger immersed in liquids, with the negative electrode made in the form of a large surface and with the positive electrode made in the form of the usual point.

Subsequently, it was established that, by insulating the positive electrode except for the small area of its point, it was possible to breakdown 10 - 30 times greater distances in water with the same voltages than without this insulation.

In practice it turned out that the use of insulation of the positive electrodes made it possible to breakdown almost three times greater thicknesses of water than air with the same voltages.

This phenomenon is easily explained by the great reduction in the total conductivity in the water due to hydrogen ions, which are the chief factor in the conductivity of water.

It was also established that grounding the part of the charge-discharge circuit before the shaping spark gaps produced small leaks and reduced the efficiency.

It was possible to show that grounding can be definitely recommended only for a circuit with two shaping ~~sgx~~ spark gaps, especially if this is carried out in the discharge part of the circuit beyond the shaping spark gaps ~~and~~ if the negative electrode is grounded.

In discharges from a set-up with a power of 1.5 kw, water in the form of cone-shaped "bowls" flew upwards at a small depth beneath the surface. Air rushed into the depressions thus formed. The stream of air bubbles rushed hissing towards the bottom of the tank, struck it, and rose upward.

~~Ems Ims~~ a single discharge at a depth of about 200 - 300 mm beneath the surface of the liquid, up to 10 - 15 l ~~of~~ water flew out, strongly ~~it~~ striking a ceiling at a height of 5 m ~~strongly~~. The air shock produced turbulence motion and strong splashing in a tank containing more than 400 l of water. 25/26

This phenomenon of purely "air cavitation" is characteristic of electrohydraulic shocks from discharges more than 70 mm long, since they could not be placed deeper

than 400 - 500 mm in the experiments which were conducted, because of the danger of destruction of the tank.

6. "Plastigraphic" Method of Studying the Electrohydraulic Effect.

During our studies, we developed a method of studying electrohydraulic shock, which is obviously suitable for studying the characteristics of other phenomena occurring in a liquid, such as electric machining, explosions, cavitational processes, and others.

This method, which we called the "Plastigraphic" method consists of recording the action of electrohydraulic shocks on plastilene objects placed in a suitable order about the discharge.

As a result, cavities (hollows) are formed in the plastilene discs, where they are preserved for subsequent observation. These give the shape and finite dimensions of the shock wave which was formed.

In addition to the use of discs, discharges were produced in plastilene cylinders which were submerged in water and through the openings of which electrodes were passed. In this case, it was found that it was necessary to raise the breakdown voltage for the same spark-gap length.

Thus, a discharge 50 mm long which easily arose at 40 kv in water, required 50 - 60 kv in a plastilene cylinder. A discharge 120 mm long, which had been

produced earlier with 50 kv, required 60 - 70 kv.

~~With~~ For open shock waves produced on one side of ~~the~~ a disc, the disc shows, ~~besides~~ in addition to, the large depressions which ~~were~~ are the traces of the shock waves, other deeper depressions with sunken and smooth edges. These are the traces of the action of cavitation shocks, which filled from one end the cavity formed after discharge. When the depth to which the discharge and the plastilene disc were emerged in the liquid was reduced, the action of the cavitation shock was greatly weakened and the depth of its marks was reduced.

An increase in the length of the discharge had a similar effect. At a given depth, the mark of the cavitation shock weakened as the length of the discharge was increased. This was a consequence of the equivalent reduction in the thickness of the liquid in which the ~~xxx~~ reverse cavitation shock was formed.

Discharges inside large plastilene cylinders were partly protected from the action of the cavitation shocks.

As the length of the discharge was increased, when the cavity inside the cylinder became large, while its plastilene wall became thin, this wall could no longer stand the action of the cavitation shock and collapsed inwards. 26/28

Thus, the plastigraphic method made it possible to observe the volume effect of cavitation shock and to ~~fxxxx~~ follow ~~the~~ their course, right up to the outburst of the

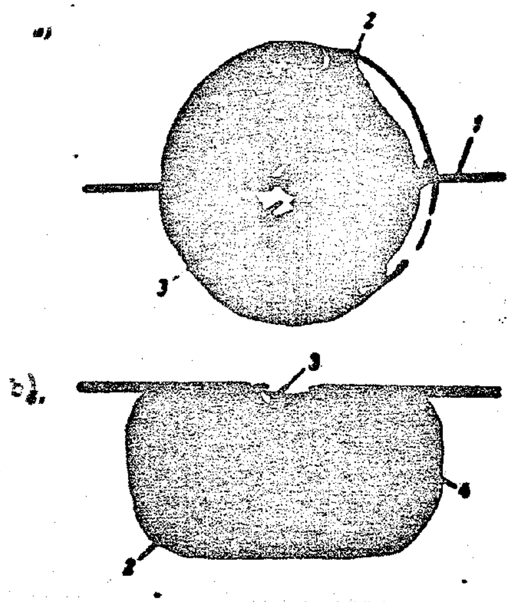

Fig. 13. Plastigraphic impression of a discharge on a disc (on the surface of which the electrodes are placed):

a- view from above; b- cross-section.

1- electrodes; 2- trace of the cavitation shock; 3- trace of the main shock; 4- plastilene.

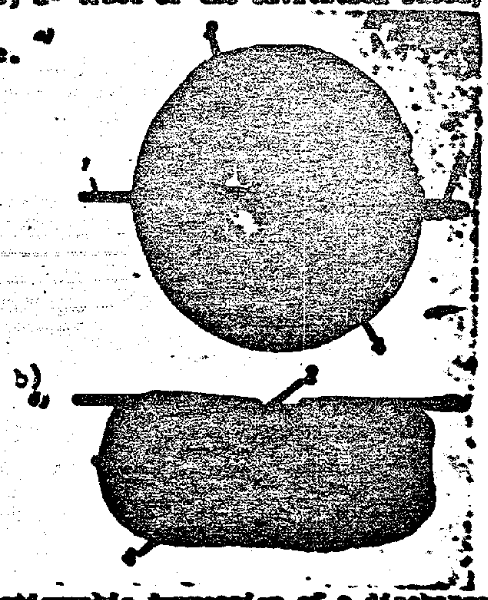

Fig. 14. Plastigraphic impression of a discharge on a disc (on the surface of which the electrodes are placed):

a- view from above; b- cross-section

1- positive electrode; 2- trace of the main shock; 3- negative electrode; 4- trace of the cavitation shock.

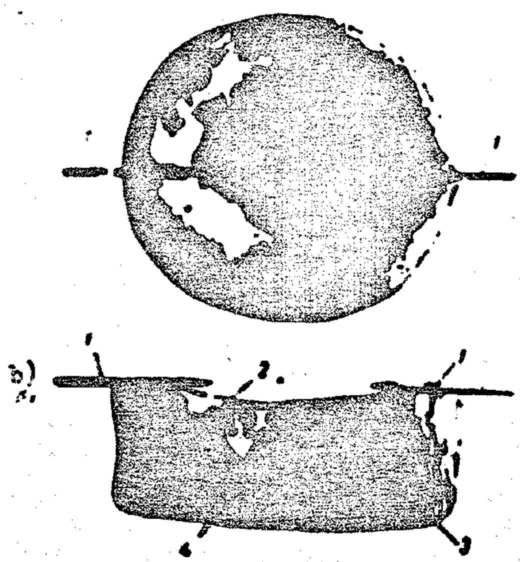

Fig. 15. Plastigraphic impression of a discharge on a disc (on the surface of which both electrodes are placed: 2 a- view from above; b- cross-section.

1- electrodes; 2- trace of the main shock; 3- plastilene; 4- trace of the cavitation shock.

Fig. 16. Plastigraphic effect of a single discharge (with the electrodes placed parallel to one another) a- view from above; b- cross-section.

1- electrodes; 2- line of the cross-section of the disc; 3- plastilene; 4- trace of cavitation shock; 5- positive electrode.

a)

b)

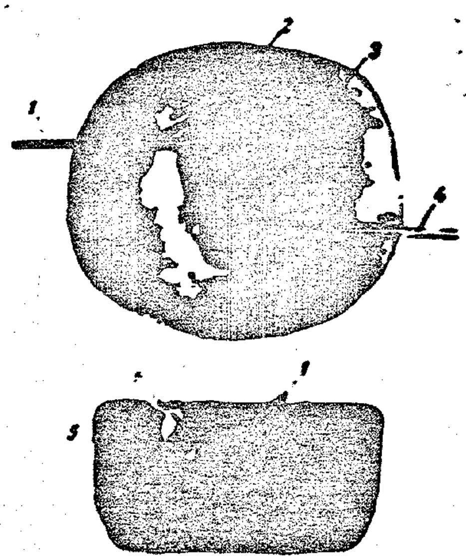

Fig. 17. Plastigraphic effect of a single shock (with the electrodes in a displaced parallel position): a- view from above; b- cross-section. 1- positive electrode; 2- line of cross-section of the disc; 3- and 5- plastilene disc; 4- negative electrode; 6- trace of cavitation shock.

a)

b)

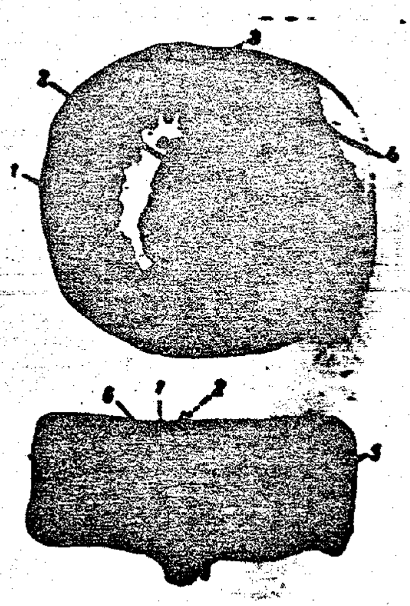

Fig. 18. Plastigraphic effect of a single shock (with the discharge perpendicular to the surface of the plastilene disc):

a- view from above; b- cross-section.

1- faint trace of action of main shock in the form of a bowl; 2- negative electrode; 3- line of cross-section of disc; 4- direction in which the upper (positive) electrode was inclined; 5- plastilene; 6- trace of the cavitation shock.

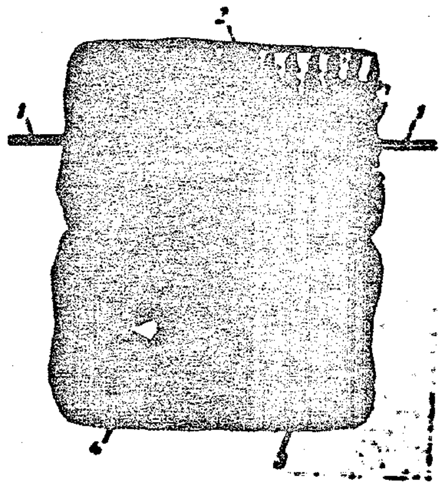

Fig. 19. Plastigraphic impression of the action of a single shock inside a cylinder:

1- electrodes; 2- plastilene cylinder; 3- central channel; 4- cavitation cavity - trace of the action of the main shock.

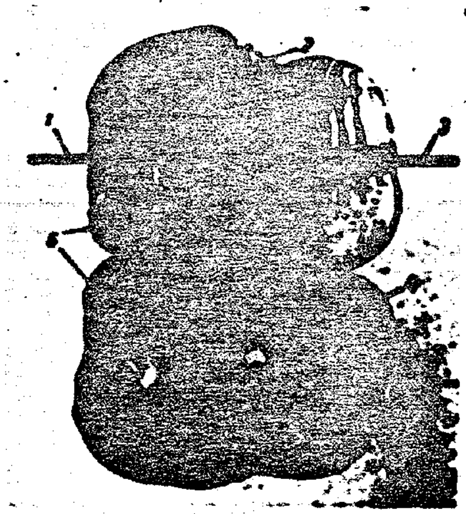

Fig. 20. Plastigraphic impression of a single shock inside a cylinder:

1- positive electrode; 2- outburst of the cavitation shock; 3- negative electrode; 4- plastilene; 5- central channel; 6- wall of the cavity.

cavitation shock of the cavity.

This method was used to study the action of electrohydraulic shock waves and the cavitation phenomena accompanying them, with the electrodes and the plastilene disc placed in very different positions.

After each single discharge, the plastilene disc or cylinder was photographed from above, and then it was cut into and a new photograph was taken in the side position.

The series of photographs (Figs. 13 - 20) was made under the conditions given in Table 3. The position of electrodes can be seen on the photographs. Except for one case described below, the electrodes were placed on the surface of the plastilene.

The plastigraphic impressions of the action of the electrohydraulic shock waves make it possible to study the distribution of the energy given off along the length of the spark.

The discharges inside the cylinders indicate that energy is given off quite uniformly along the length of the discharge. It is possible that somewhat more energy is given off at the end of the spark, towards the electrodes.

The discharges on discs make it possible to establish whether more or less energy is given off with various electrodes.

All of the photographs given show the result of the action of an electrohydraulic

shock wave~~s~~ and the accompanying cavitation shock produced as a result of a single pulse.

The entire cavity is formed at once by the same process, and none of the phenomena of gas and vapor formation are observed. The experiments showed that these cavities are regular geometric figures, and that they have smooth walls without any asymmetric depressions or other irregularities.

The foldings sometimes found are caused by the compression of the cavities ~~through~~ under the action of the cavitation shock, following the expansion through the main shock wave. This is noticeable only in very large cavities.

It can be supposed that the disintegration zone (the B zone) has a shape ~~in~~ and dimensions close to the shape ~~in~~ and dimensions of the cavities given in the photographs.

For the work of many devices using the electrohydraulic effect, the fact that cavities, i.e., a considerable linear displacement of liquid, are formed will be the great determining factor rather than the shock wave. This holds for the cumulation effect and for the work of sprayers, pumps and other devices.

In almost all plastic materials - bitumen, pitch, wax, clay, and others - cavities are also formed. However these materials either emulsify (bitumen, clay), or crack (bitumen, pitch, wax), or else have many particles torn off (wax, clay).

<u>Conditions of Plastigraphic Experiment</u>

TABLE 3.

1	2	3	4	5		8
				6	7	
11	[illegible]	0.2	12	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	12	13	11	[illegible]
[illegible]	[illegible]	0.2	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]
[illegible]	[illegible]	0.7	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	12	[illegible]	[illegible]	[illegible]
	[illegible]	0.7	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.7	[illegible]	[illegible]	[illegible]	[illegible]

Notes

Large activity of cavitation near the negative electrode.

The cavitation is more active ~~mm~~ ~~at~~ the negative electrode.

The cavitation shock is greatly weakened; the main shock, considering the small capacitance is scarcely changed; same ~~x~~ activity of cavitation.

Both shocks are clearly manifested; no predominace of activity at either electrode.

The cavitation shock is weakened, since a 300 mm layer of water is insufficient for its development. Stronger activity at the negative electrode.

More active cavitation at the positive electrode.

More active cavitation at the negative electrode.

The upper, positiveelectrode is inclined at an angle of 30° in the direction shown by the arrow on the plastilene. This has realted in a large activity of cavitation in this direction.

The cavity is strictly symmetric with respect to the electrodes and the spark.

The cavity is strictly symmetric with respect to the spark.

The entire cylinder is compressed on all sides. The rupture of the cavitation shock inside the cavity is clearly seen.

1) Fig. No. 1; 2) Voltage in Kv.; 3) Capacitance in mF; 4) Spark length mm; 5) spark gaps; 6) left (+) mm; 7) right (-) mm; 8) depth of submersion in mm.

Plastilene is most convenient since it has no impact brittleness at room temperature, it practically does not emulsify, it does nt dissolve in water, and particles do not tear off from it.

Thus, by generalizing the above facts, we can regard the experiments as having established the following series of qualitative relationships, namely:

1) within certain limits, the length of the spark in water depends on the main capacitance of the circuit;

2) the arising of a breakdown in water depends on the area and polarity of the electrodes. An increase of the area of the negative electrode in contact with the water favors the development of a breakdown and the production of a long spark. To a still greater extent, these effects can be produced by reducing the active surface of the positive electrode. In the opposite cases, no breakdown occurs;

3) the voltage at which the breakdown arises depends on the electrode material, increasing in the order - steel, dural, g brass, copper;

4) other conditions being equal, the length of the spark in the liquid increases with increasing steepness of the wave front of the pulse;

5) the arising of a breakdown depends on the concentration of electrolytes in the water, but the steeper the wave front of the pulse and the shorter the wavelength, the larger is the concentration at which the discharge arises;

6) the disintegrational effect depends on the shape and especially on the sequence of the wave front of the pulses. In turn, this is effected by changes in a) the length of all the spark gaps; b) the amplitude of the current and voltage; c) the capacitance C, the resistance R, and the self-inductance L of the discharge circuit and especially of its right half; d) the C, R and L connected parallel to the main spark gaps;

7) the degree to which the repetitions of the electrohydraulic effect are identical in each discharge depends on the conditions of work of the circuit; from the plastigraphic data, it seems that the spread of values can be detected only with an oscillograph;

8) when the circuit is grounded beyond the shaping spark gap, and, in particular, in the branch of the negative electrode, the leaks are practically insignificant.

Chapter III

DEVICES USING THE ELECTROHYDRAULIC EFFECT

7. Electrohydraulic chisels and boring devices.

A) Electrohydraulic chisel.

To study the destruction of non-metallic materials by the electrohydraulic method, we prespared a device which we call the "electrohydraulic chisel".

This chisel consists of a textolite head out of which steel-wire electrodes of ϕ 2 mm emerge.

The head is fitted on a textolite rod, which rotates freely in a socket fastened to a crossbar of the bath. To keep the chisel from being thrown up after each pulse (recoil), a load of 1.5 kg is placed on the textolite rod.

When the current is switched on, discharge is formed between the end of the electrodes and the chisel sinks into the material under test. In this way, a corundum circle 100 mm thick was pierced in 3 - 4 minutes with a frequency of 50 - 60 pulses per minute and a spark length of 25 mm. An external view of the chisel is shown in Fig. 21.

We also tested a chisel with a spark length of about 100 mm, but we had to abandon it because of the rapid destruction of the tank.

In working with a-c current at a frequency of 100 pulses per second, we also tested four chisels with a spark length of 8 - 10 mm. These chisels pierced abrasive

wheels of any strength to a depth of 40 - 50 mm in 2-3 seconds, the power required for this being 100 W.

With rare exceptions, the shattered stones formed fine dispersed particles with a grain size no greater than 1 - 2 mm.

This same chisel chips diabase and marble considerably more slowly (3 - 5 mm/min at 200 w).

Quartz, glass, and other brittle materials are easily chipped, with a rate of 30/31 15 - 30 mm/min.

Rocks with conducting or semi-conducting inclusions are chipped at an increased speed.

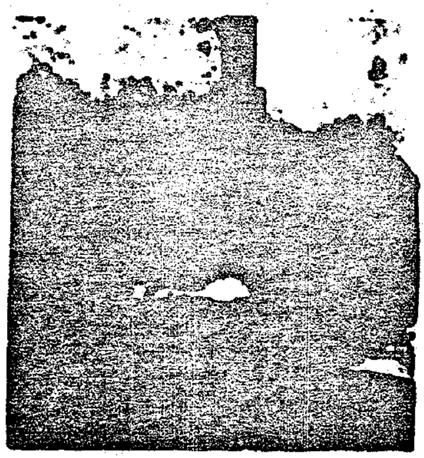

Fig. 21. A chisel in a tank in operation, at the beginning of chiseling. On the bottom, sparks can be seen at the ends of the electrodes.

(Photographed through the wall of the tank).

Fine-crystalline rock and materials of the type of solid solutions can be chiseled more easily than quartz-crystalline rocks, fibrous rocks, and certain schistous rocks.

In the disintegration of rocks, the determining factor is not the hardness of the rock, but its brittleness.

B. Electrohydraulic bore.

To obtain regular holes in non-conducting materials, the special device shown in Fig. 22 was designed.

Inside the metal bit, which is tuffed on the end, there is a textolite insulation with an opening for the flushing liquid.

In the center of the insulator, the (+) - electrode freely rotates in a tubular bushing. The current of this electrode is supplied by a side contact. The lower end of the electrode is bent at a right angle for 5 - 10 mm. Near the bottom of the bit, the tube has holes so that gas and vapor formed by chance can emerge. 31/32

When voltage pulses are fed to the bit and the electrode, discharges arise between the bent end of the electrode and the tuff of the bit nearest to it.

When the electrode is rotated by a special motor, the dischargesx cover the entire lower end of the bit, travelling from tuff to tuff in succession without ever stopping. The electrohydraulic shock waves which arise in each discharge destroy

the rock on which the bit is placed.

The pulverized rock emerges from in between the teeth and through the gaps between the tube and the walls of the opening, from where it can be washed out by water fed under pressure into the hollow parts of the instruments.

When the electrohydraulic bore remains stationary (except for the lower part of the electrode), it makes holes of regular circular shape in any non-conducting material.

The test model of the instrument has an engine with the power of 3 w which rotated the electrode with ~~the~~ a speed of 10 rot/min. The bore was fed by pulses with a capacitance of $0.2 \mu f$. The length of both shaping spark gaps was 10 mm. The voltage was 25 - 30 kv.

The tube diameter was 30 mm, while the holes produced varied from 40 to 50 mm in diameter in rocks of various hardness. This eliminated the danger that the instrument would be wedged in the hole. The walls of the holes were not smooth, but were rough within tolerated limits.

On top of the bore, a 1.5 kg weight was placed. The total weight of the bore 32/33
amounted to 2.5 kg. The height to which it jumped up in recoiling did not exceed 5 - 10 mm, and this decreased to 3 mm as the bore sank into the rock. However, at a higher frequency of the pulses, the instrument was in a sense "suspended" above

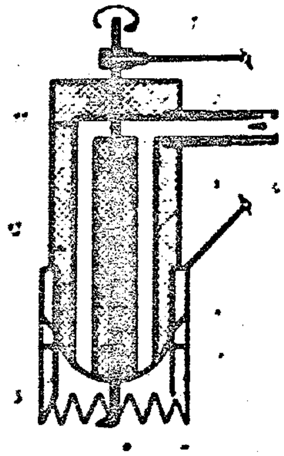

Fig. 22. Diagram of the design of one of the continuous cutting bores.

1- current lead to the central rotating electrode; 2- pipe supplying the flushing (and working) liquids; 3 and 9- ducts leading the flushing liquid into the body of the bore; 4- current lead for the bit of the bore; 5- openings in the bit for the emergence of gases; 6- bit; 7- teeth of the back end of the bit; 8- end of the central electrodes, ~~bending to~~ bent at a right angle; 11- central rotating electrodes (+).

the face it was cutting.

The bore sinks into the rock under its own weight. For this purpose, it moves frequently on guides set up on a cross beam of the tank.

One of the central components of the bore is the insertion piece of soft rubber tubing which surrounds the tubular bushing of the central electrode and emerges beyond the lower end of the textolite shaft of the head. Thus, the rubber insertion piece extends partly into the disintegration zone, since the textolite

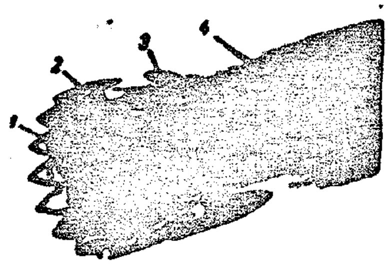

Fig. 23. View of the lower end of the bit head of a bore ~~[illegible]~~ after making 5 holes 80 mm deep in a solid corundum ~~[illegible]~~ wheel.
1- bent end of the central electrode; 2- tooth of the bit end;
3- opening in the bit for the emergence of gases; 4- shaft of bit.

would rapidly become unusable if it extended into this zone.

The lower end of the head which has made five holes to a depth of 80 mm each in a hard coarse-grained corundum abrasive wheel is shown in Fig. 23.

It can be seen from the photograph that neither the tube nor the central electrode have any traces of erosion or wearing, even though they are made of soft steel.

Fig. 24 shows another model of a bore in a tank at the time when the openings are beginning to sink into the object. On one edge of the tube, sparks can be clearly seen, which then cover the entire perimeter of the bit. An example of the work of this bore is shown in Fig. 25, which shows a hole made in a corundum abrasive wheel.

It was determined in the studies that the bore can make holes even in elastic

material, such as soft rubber. Soft rubber is torn out in pieces with sharp edges, which have the appearance of breaks in a brittle material. The thickness of the pieces cut out is 5 - 6 mm.

Experiments showed that, after the bore has sunk into the rocks, it is possible to break either the entire specimen of rock, or just its lower part, by operating the bore with a large capacitance. Thus, with the same power unit, it is possible to make holes to a small given depth and then to make a hydraulic "explosion" in this bore hole by sending two or three pulses at a large capacitance.

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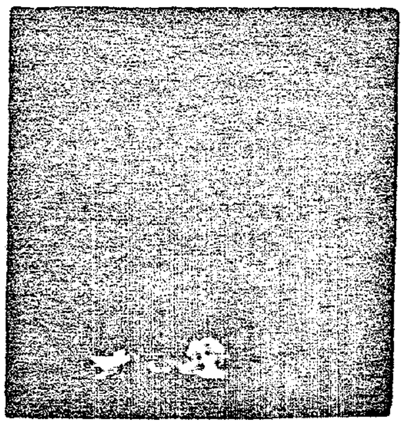

Fig. 24. View of the bore as it starts boring. Beneath the bit, discharges can be seen.

(Photograph taken through the wall of the tank).

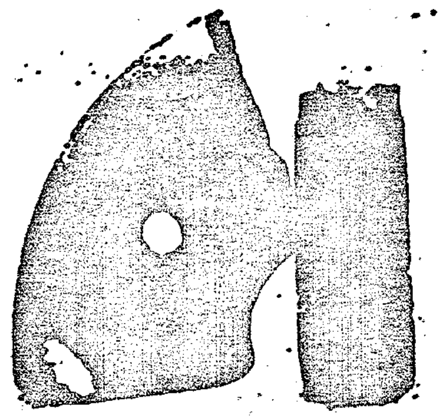

Fig. 25. Hole of Ø 40 mm made by the bore in a corundum wheel. 34

Table 4 gives data on the actual and theoretical drilling rates of different rocks.

Since the frequency of 100 cps does not represent any sort of limits and frequencies of 500 - 1000 cps can be easily obtained, it can be supposed that the drilling rate of holes in rocks and similar materials can be considerably increased. 35 36

C. Bore for digging out specimens.

To produce ring-shaped holes with a central core, the bore model shown in Fig. 26 was tried.

In this bore, an internal cylinder, whose bottom end is cut off frontwise and serves as a discharger point, rotates with a speed of 10-15 rot/min, and in this way the perimeter at the end bit is covered by discharges between the point of the cylinder

Drilling rates of the electrohydraulic bore in various materials and rocks

spark length 7 mm, pulse frequency 120 per min.

1 [illegible]	2 [illegible]	3 [illegible] 6 [illegible]	7 [illegible]	4 [illegible]	5 [illegible] 8 [illegible]	9 [illegible]
[illegible]	0,1	1.	1.	10 [illegible]	0,5	0,5
30	0,1	1.	1.	11 [illegible]	3	150
30	0,1	1.	1.	12 [illegible]	10	500
25	0,2	10	10	13 [illegible]	15	750
25	0,2	10	10	14 [illegible]	20	1000
25	0,2	10	10	15 [illegible]	30	1500
25	0,2	10	10	16 [illegible]	50	2500
25	0,2	10	10	17 [illegible]	100	6000
25	0,5	10	10	18 [illegible]	250	12500

19 [illegible]
20 [illegible]

1) Voltage Kv; 2) Capacitance mf; 3) Spark gaps; 4) Rock or Material; 5) Rate of immersion in mm/min at a frequency (see 8 and 9); 6) left (+) mm; 7) right (-) mm; 8) 2 cps (exp); 9) 100 cps (comp); 10) Industrial rubber; 11) Diabase; 12) White marble; 13) Mirror glass; 14) Fused quartz; 15) Corundum circle; 16) Quartz clay shale; 17) Cambrian clay[2]; 18) Argillaceous soil.; 19) The bore sinks into fragments of rubber; 20) The boring rate can be increased by increasing the weight of the bore.

and the nearest tooth of the bit.

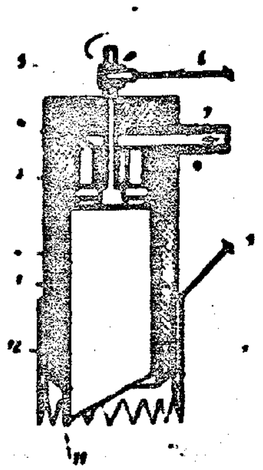

Fig. 26. Diagram of one of the bore models for producing ring-shaped holes with a central core.

1- textolite insulator; 2- cavity into which the bore enters; 3- outlet of the duct for the flushing and working liquid; 4- duct supplying the liquid; 5- axis of the internal rotating electrode cylinder; 6- current lead to the central electrodes; 7- pipe supplying the liquid; 8- current lead to the bit of the bore; 9- openings in the bit for the emergence of gases; 10- teeth of the bit end piece; 11- protuberance of the lower slant-cut part of the internal rotating electrode cylinder; 12- bit of the bore;

The core formed in drilling goes into the internal cavity of the cylinder, from which it can be removed. Water is supplied through an opening in the bore shaft.

With the bore of this type, it becomes possible to obtain holes of any diameter.

For a cutting width of 50 - 80 mm, no voltages greater than 50 kv are required for the work of this instrument.

It was demonstrated experimentally that, with a voltage of 70 - 100 kv, a capacitance of 0.7 - 1.0 μf, and spark length up to 220 - 250 mm, it is possible to obtain completely cut ~~off~~ out holes with a diameter up to 450 - 500 mm.

As we have already mentioned, the hardness of the rock that has no significance when holes are made in them according to this method.

8. Electrohydraulic cutting instruments.

To investigate the possibilities of cutting through a non-conducting material, we designed a device with which we could conduct experiments on cutting quartz rods, ceramic and porcelain tubes, and similar materials.

From the side, a special "cutter" was held against the slowly rotating quartz rod by means of a special compression spring. The end of the cutter's electrodes, between which the discharge took place, slid continuously along the surface of the specimen, following its irregularities in rotation.

The object being cutt and the cutter were placed in a pyrex tank ~~of [illegible] glass~~ filled with water.

Fig. 27 shows three types of cutters used in the experiments.

The cutting was conducted at a frequency of 100 pulses per sec ~~on~~ with a-c current, with a capacitance of 0.01 - 0.02 μf and a power consumption of ~~[illegible]~~ about 100 w.

The cutting effect turned out to be excessively strong. At the start of the cut, there were dents up to 1 - 3 mm deep and up to 6 mm wide, while further on, at a depth of 5 mm, the dent narrowed to 2-3 mm. After 3 - 5 min, the quartz rods split exactly along the cutting line. Ceramic and porcelain materials were also cut with this device.

The cutting was conducted at a voltage of about 30 kv, which was considerably greater than that required.

Fig. 28 shows a fused-quartz rod 45 mm in diameter, on which 3 cuts were made: the upper one - with a power of the order of 300 w; the middle one - with a power of 150 w; and the lower one - with a power of 100 w. The last two incisions were made to a depth of 8 - 10 mm, after which the discs split off along the cuts.

At large powers (up to 300 W), the specimens broke in two before completing half a revolution. The upper end of the specimen shown in Fig. 28 is a consequence of this type of "cutting".

The experiments showed ways of designing devices for longitudinal and transverse cutting of blocks of stones and cutting them out from quarries or in subsequent finishing.

Thus, a simple "electrohydraulic milling cutter" was tested for finishing the surfaces of stone blocks.

The milling cutter is formed by a series of spark gaps fastened to a strip of textolite and connected in series. These rotate above the surface being finished and at the same time move forward parallel to the surface. The test of the milling cutter gave satisfactory results. 37/38

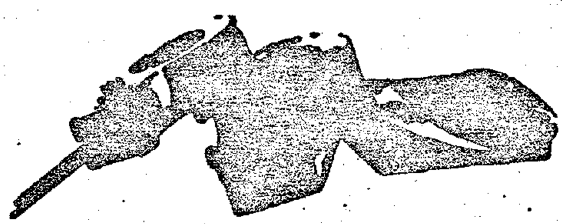

Fig. 27. Three types of cutters used for cutting non-conducting materials in water.

Fig. 28. View and shape of the incision of a fused-quartz rod. (The upper part of the rod, which splits along an incision, has been removed).

38/39

9. Electrohydraulic sprayers and pump.

If vessels in which electrohydraulic shock waves are produced are hermetically sealed, the pressure in them will increase greatly. If openings are made in the walls of these vessels, a strong ejection of liquid can be expected from them.

This assumption provided a basis for study the application of the electro-

hydraulic effect to the feeding and atomising of fuel in internal combustion engines.

For the experiments, a device, an external view of which is given in Fig. 29, was prepared.

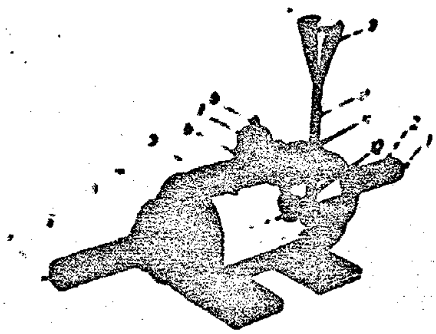

Fig. 29. Device for ~~feeding~~ supplying and atomising liquids.

1- electrode terminal; 2- textolite insulator; 3- clamping washer; 4- brushing; 5- casing of the device; 6- connecting pipe; 7- tightening nut; 8- deisel-fuel atomizer; 9- funnel for the liquid; 10- tube of the funnel; 11- stop cock; 12- tube to the duct inside the device.

Two long textolite insulators with electrodes passing ~~them~~ through them were inserted inside a cone-shaped fitting inside two bowl-shaped steel bushings, which screwed into a cylindrical steel casing.

This design made it easy to change the volume of the internal cavity and also to change the length of the main spark gap inside the cylinder.

On top of the cylinder, a connecting pipe with a 10-mm opening was screwed on.

On it, ordinary deisel-fuel atomizers were installed and held with a special nut.

The liquid flows under its own pressure through the funnel into the channel drilled in the body of the cylinder. The channel had a cross-section from 5 to 8 mm and made two turns at a right angle on its path. These turns almost completely damped the pressure shock wave formed inside the cylinder. In addition, the channel could be bypassed with a special valve.

A weak point in this device was the fastening of the front end of the electrodes. After several pulses, the electrodes would be torn out from the insulator and would break, putting the machine out of order.

Apparently the electrodes were pulled out by the action of shock waves, which reflected off the bowl-shaped bushing and focused on to the end of the electrodes emerging from the textolite because of their central position. Another type of support, in which this factor was taken into account, turned out to be more reliable.

The internal diameter of the cylinder was 100 mm and its length 250 mm, while the variable volume of the internal cavity could be changed from 800 to 1600 cm^3. Discharges up to 80 mm long could be produced inside the cavity.

When a spark discharge only 20 mm long was produced inside this device, the upper part of the atomizer head was torn off (fig. 30). From computations, this required a force of about 5 tons.

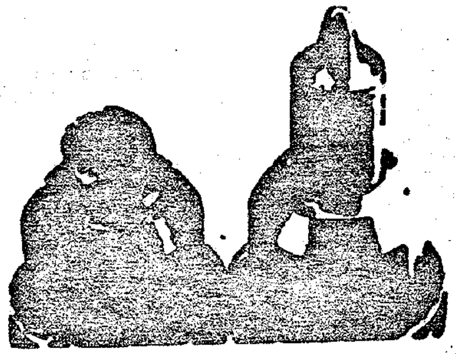

Fig. 30. Destruction of a deisel-fuel atomizer: breaking off of the head of the atomizer as a result of ~~the~~ a spark discharge 20 mm long.

Considering that the pressure developed in the zone of the spark discharge arose in a volume of more than 1000 cm^3 and that the actual discharge took place at a distance of about 100 mm from the spout of the atomizer, it can be concluded that the pressure generated in the given volume is immeasurably greder than that necessary for feeding fuel.

A reduction of the spark length to 15 mm entailed the breaking off of the spout of the atomizer. Again this indicated an excessively high pressure. Only

when a spark 10 - 12 mm long was used did the atomizer cease to break off, and the device began to operate stably.

Through all six openings, each with a diameter of 0.15 mm, in the nose of the atomizer, thin streams of finely atomized water emerged with a frequency of the electrohydraulic shocks. These streams were in the form of bluish misty jets. They rapidly expanded to a diameter of 80 - 100 mm and flew radially to a distance of 300 - 400 mm from the spout of the atomizer (fig. 31).

With the atomizer removed, a cone-shaped column of water mist flew out through the 10-mm opening in the connecting pipe to a height of 5 m. The diameter of the mist jet attained 1 m at the base of the cone, and the amount of liquid emitted in one pulse amounted to about 50 cm^3.

If the spout of the atomizer was sawed off in such a way as to form an opening 1 - 1.5 mm in diameter, the jet of water mist attained a height of 1.5 - 2 m. The diameter at the base of the cone decreased 1/2 meter and the volume of liquid ejected in a pulse to 2 - 5 cm^3.

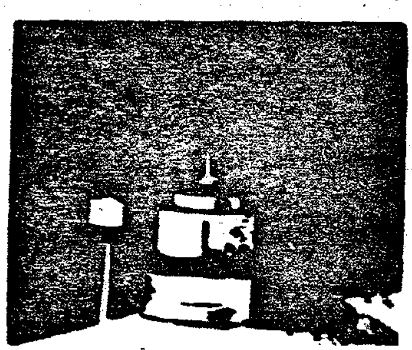

Fig. 31. Jets of atomized liquid emerging from openings in the spout of the atomizer.

The experiments described above were conducted with a voltage of about 30 kv, a capacitance 0.2 f, shaping spark gap of 8 mm each, and a frequency of 50 pulses per min.

In testing different liquids in the experiments, we decided to use industrial water for simplicity, especially since it is considered more difficult to atomize it, because of its high surface tension, than benzine, mazut, or kerosene.

When the circuit was properly adjusted, no phenomena of gas and vapor formation, which would disturb the process of feeding and atomizing, were observed. Thus the valveless feeding of the liquid into the cavity of the atomizer was justified.

From the experiments which we conducted, it follows that this system of feeding and atomizing fuel can be used in internal combustion engines if ~~the~~ a spark length of 10 - 15 mm, capacitances not exceeding 1 μf, and voltages of 20 - 30 kv are used.

This voltage is easily attainable with large ignition coils and with a power unit such as those used in internal combustion engines.

By producing pulses in the primary circuit and by distributing them in a secondary circuit by means of an ordinary ~~distributor~~ trembler, one can obtain and expend economically the high instantaneous power required for feeding and atomizing the fuel, considering that the power will be required for only a few seconds out of each minute [41/42]

of operation of the engine.

Another device which was studied in a crude model is the "high-pressure electrohydraulic pump" (Fig. 32).

A fluid under a small pressure is fed into a tube, open on both sides, from one end. Along the length of the tube, at definite intervals, 5 - 7 or more spark gaps are placed, each of which represents in a sense a degree of compression.

Discharges distributed by a trembler cover the entire series of spark gaps in sequence, a discharge being repeated at the first spark gap as soon as a discharge, ~~taking turns~~, arises at the third or fourth spark gap alternately.

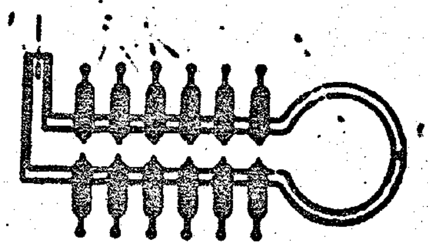

Fig. 32. Diagram of a possible type of high-pressure pump.
1- supply of liquid flowing under gravity; 2- insulators; 3- electrodes; 4- working cavity of the pump; 5- receiv[illegible] 6- small-diameter opening for emergence of the jet.

Thus, staggered compres[illegible] begin to move towards one of the ends of the tube, gradually r[illegible] the pressure of the liquid, whereas there is no such

motion in the direction towards the other end of the tube.

If a receiver is connected to the open end of the tube, the pressure ~~x~~ in it will increase. Since the wave travelling towards the opposite end has a reverse sequence and can emerge into the atmosphere, it is rapidly damped.

By giving the volume about each discharge spark gap a shape such that the shock wave will travel more easily towards the ~~xxxxx~~ receiver than in the opposite direction (or by using special ~~&~~ valves), it is possible to strengthen the effect.

We tested a system having only four spark gaps. The sequence of their pulses ~~xxx~~ were set by means of a trembler. The internal diamter of the tube amounted to 8 mm, the spark length to 3 - 5 mm, and the voltage was about 30 kv. In this tube, there is a strong ejection ~~f~~ of liquid from one end, and none from the other. This indicated the directional strenghening of the pressure and showed that the principle of the pump is correct.

10. Other devices. 42 43

~~From~~ Of the other tested devices, let us mention the device for straightening abrasive wheels.

The liquid, which is fed through a cavity inside a textolite "~~shimmer~~ finger", flows out through an oval opening on its front end, above two thin electrodes placed at a

distance of 1.5 mm from one another.

The front part of the finger is shown in Fig. 33. When an abrasive wheel is rotated in the immediate ~~x~~ vicinity of the head, a layer of liquid is formed in which the discharge takes place.

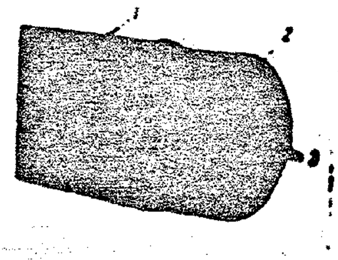

Fig. 33. Front end of the head of the device for finishing and straightening abrasive wheels.

1- casing of the device; 2- opening for the outflow of the working liquid; 3- electrodes.

Venelt
An induction coil with a ~~[illegible]~~ interupter was found to be most suitable for supplying the device. Without this, it was difficult to obtain the high frequency of the pulses which is necessary to level a rapidly rotating wheel.

In the experiments, still another device was tested, designed to study the stability of textolite for use as the membrane of an acoustic radiator.

Between two thick plates of textolite, two laminated electrodes are placed. After this, the plates are tightly bolted together ~~[illegible]~~ and the entire device is 43/44

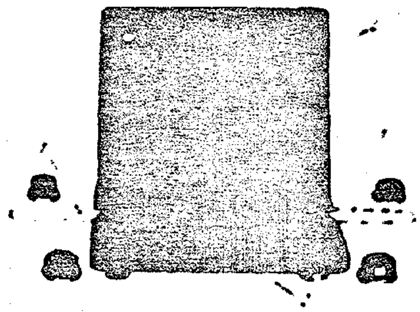

Fig. 34. Device for studying the stability of textolite for use as the membrane of an acoustic radiator (in ~~the~~ dismantled form).

1- electrodes; 2- textolite plate.

immersed in water to a depth of 400 mm.

A picture of the device in dismantled form is shown in Fig. 34.

During the discharges, ~~the~~ protuberances of water up to 10 cm above the surface of the water were observed in the tank.

As a result of the action of 100 electrohydraulic shocks from a spark 20 mm long, a white spot was formed on the surface of the textolite, with a layer of resin partially cleared from the cloth. The textolite did not disintegrate in this

process.

Experiments also demonstrated the possibility of producing inscriptions on solid materials by using the electrohydraulic action of discharges.

Despite its small power (about 3w), an electrophorus turned out to be a ~~mf~~ sufficient source of power for this purpose, and with a capacitance of 0.005 μf it was possible to make an inscription on a thermal corundum die. With the ~~electro-~~ electrophorus, it was possible to obtain pulses every 5 - 10 sec.

The letters of the inscription were made in the following fashion. The two electrodes were adjusted to the required ~~point~~ position by hand and were held ~~a~~ there until the discharge. Each discharge produced a dent about 0.1 - 0.2 mm^3 in volume.

In the experiments thermal explosions of thin metal wires were produced in water. These wires were vaporized by the action of the pulse. In terms of their external manifestations, the hydraulic shock waves produced~~in~~ in these experiments were comparable with ordinary shock waves. This shows that there exists a possibility that these shock waves may find some practical application, as, for instance, in geophysics.

We conducted experiments on the grinding and pulverization of various hard rocks and other materials. The data obtained ~~made~~ made it possible to build an experimental stone crusher and to conduct a special investigation of this matter.

Using a simple device with the 10-15 w apparatus, we conducted experiments on the [illegible] production of holes with a small diameter in solid materials: electro-corundum, quartz, and others. So far, we have obtained no holes smaller than 3 mm. The drilling rate amounts to 1 - 2 mm/min.

With the same apparatus, we easily obtain colloidal solutions of metals in water, benzine, ether, and other liquids.

Chapter IV

PROSPECTIVE USE OF THE ELECTROHYDRAULIC EFFECT

From the date of the studies, it appears possible to utilize the electrohydraulic effect in other technological applications as well. Here we find it necessary to mention only a few of these possibilities.

Experiments on the production of discharges inside piston devices filled with a liquid reveals a powerful impelling force produced on the piston by the electrohydraulic shock waves.

This makes it possible to speak of the possibility of using the electrohydraulic effect in the construction of simple, compact forging hammers for cold treatment of metals.

On the same principle, it is possible to build small percussion devices and rotating percussion devices - chisels, stamps, crow bars, shovels, and perforators.

In the design of these instruments, it is necessary to take into account the need for placing the high-voltage part of the circuit inside these instruments and for supplying these instruments with a low-voltage pulse current.

A diagram of a forging hammer is shown in Fig. 35.

The space above the piston in this machine has a free outlet into the atmosphere through a channel and through a tank filled with liquid. The small amount of gas and

vapor which can form in adjusting the machine is freely eliminated through this channel from the cavity of the cylinder.

In one of the possible designs of this machine, the~~m~~ machine can drop down freely on the object under treatment and hold itself on this object by its own weight, producing the required deformation by a series of rapidly succeeding flows.

With this type of design, the mass of the piston must be considerably less than the mass of the entire machine, which rests freely on the object.

If there are several rectangular turns in the channel connecting the cavity of the cylinder with the tank and with the atmosphere, the shock wave will be completely damped and the loss of pressure inside the cylinder will be avoided. 45/46

On the basis of the experiments, in which average pressures definitely greater than 2000 atm arose inside a volume of about 1500 cm^3, it can be assumed that the total pressure exerted on a piston with an area of 100 cm^2 will exceed 200 tons.

It is not necessary to seal the cylinder, the piston, the chambers, the leads, and other components by precision grinding, in these forging hammers, as distinguished from the usual type of forging, hammers.

It is only necessary to avoid ~~in~~ leaks, since even a fairly long slit 1 - 5 mm wide is an insurmountable obstacle for pressure pulses.

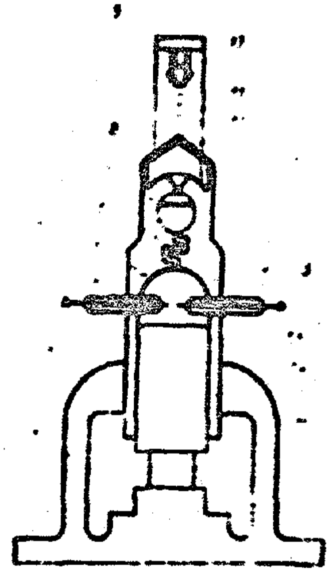

Fig. 35. Theoretical diagram of a possible design of a forging hammer.

1- anvil; 2- mount; 3- electrode; 4- insulators; 5- cavity with liquid; 6- damping channel; 7- tank with liquid; 8- funnel; 9- cantilever; 10- suspension block; 11- cantilever supports; 12- suspension links; 13- piston; 14- cylinder; 15- object undergoing deformation.

However, ordinary seals in the form of cupand gaskets are required in all cup designs, whether the design given above, or some other, such as a single-chamber valve pump with an air shock absorber to smooth the shock pulsations.

From the experimental data, it is obvious that the electrohydraulic effect can be used in cold-hardening the surface of metal objects. ~~Without~~ With our method, it appears that it will be possible to cold harden the surface of internal cavities,

which is impossible to do by other methods.

If the traces of individual blows are broad enough, they will merge with one another and will overlap when the object is fed to the machine. This will ~~preserve~~ keep the surface of the object smooth.

The use of large powers makes it possible to speak of the possibility of obtaining deep hardened layers.

It is possible to harden both flat and spherical surfaces, by using existing stands and devices equipped with water tanks.'

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A sketch of an instrument for cold hardening external cylindrical surfaces on a lathe bench is shown in Fig. 36. The hardening instrument is fastened in the bench support, while the object being hardened is placed in the shock or in the centers.

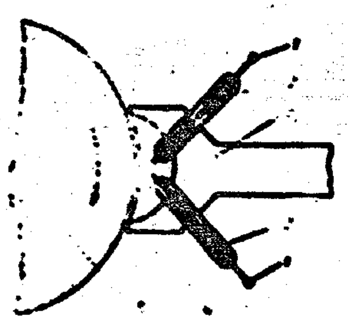

Fig. 36. Theoretical diagram of a device for cold hardening round objects. 1- electrodes; 2- insulators; 3- holder with a focusing device; 4- cumulating sphere (cavity filled with liquid); 5- object undergoing cold hardening.

A diagram of a device for cold hardening internal cavities, such as the walls of an engine cylinder , is shown in Fig. 37. To eliminate harmful stresses acting on the device in one direction, two opposite spark gaps, connected in series, are used. These breakdown practically simultaneously.

Each spark gap is located inside a spherical cumulative hollow whose wall is at a greater distance from its discharge zone than the radius of the disintegration zone.

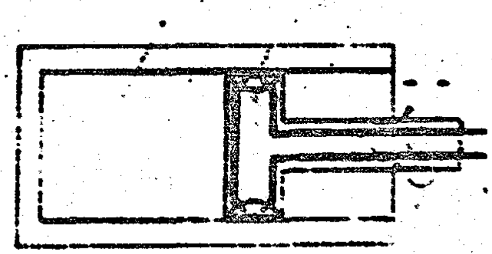

Fig. 37. Theoretical diagram of a possible design of a device for cold hardening an internal cylinirical cavity.

1- cavity filled with liquid; 2- cumulating spheres; 3- electrodes; 4- casing of the cold-hardening device; 5- the object undergoing cold-hardening.

This type of cold-hardening can be used for, in particular, axes, rollers, journals, internal and external surfaces, ball bearing races, and balls, the cavities of engine cylinders, bench guides, and other parts of machines, benches, and mechanisms.

In our experiments, we tested a model of a unique type of "saw" - an immobile instrument for cutting linearly through any kind of non-conducting material or rock. Made of a textolite blade, it represents in effect a "divided" working spark gap. A diagram of this saw is given in Fig. 38. 47/48

The main discharge is broken down into a series of short individual discharges. Without losing its strength of action, it is more localized in a narrow strip in a given direction.

The end electrodes of the "saw" are connected to the electric circuit.

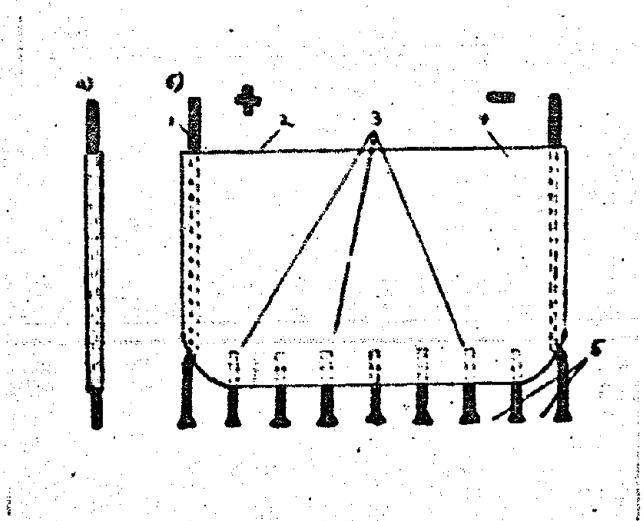

Fig. 38. Theoretical diagram of the design of an instrument for rip sawing non-conducting materials.

a- side view; b- front view.

1 and 4- electrodes; 2- insulating plates (textolite); 3- intermediate electrodes inserted in the insulator; 5- series spark gaps.

By connecting ~~conducting~~ in series several of these saws, it was found possible to ripsaw any length (when the individual saws are fed from the circuit), and to cut out sections of triangular, square and trapezoidal shapes.

In theory, this method can be used to saw off objects of any configuration and cross section into blocks which can be easily removed and transported.

The water can be supplied in several ways, one of which is to supply ~~ing~~ it through the cavities in the end electrodes or through special holes in the body of the saw.

When camouflet cavities are formed in moistened soil by powerful discharges from a simple chisel-like device, it is possible to drive in piles and a rabbet by providing the pile with a special tip and by using an armature in the body of the pile for the electrodes. For the working medium, local ground and underground water can be used.

The weight of the pile and its vibration during the shock waves will help it to sink into the ground.

Tests with a model confirmed the simplicity of this system.

In addition to the driving of piles and a rabbet, the electrohydraulic method can be used for vibrational packing of wet soil beneath the surface, or, on the contrary, for stirring up its frozen surface layer (frozen crust) with a "blast" from below (of course under the condition that the soil is sufficiently saturated

with water).

In certain cases, electrohydraulic devices can be used as easily regulated pulse transmitters of simple design.

In a number of experiments, the possibility of using the effect in devices performing a rotational or translational motion was demonstrated. Several types of engines, using ~~both~~ either the direct action of the electrohydraulic waves or the reaction to them, can be used for this purpose.

Experiments showed that wood placed in the disintegration zone was broken up into separate filaments. This also presents a certain practical interest.

The experimental data provide a basis for using the electric circuit in establishing a new procedure of determining the electric strength and conductivity of ~~the~~ a liquid. When the action of the pulse electric field and current on ~~the~~ a liquid is very short, the ordinary changes occurring in ~~the~~ a liquid from an electric field and current and the resulting changes in the electric ~~fun~~ conductivity ~~of the~~ and electric strength will not appear.

When discharges are produced in the midst of metal powder, filings, or chips placed in a liquid, it is possible to observe an intensive dispersion of the metal into a fine dispersed suspension. This indicates that it will be possible to use this method to produce any kind of micropowder and colloidal solution of different metals.

If large (3 - 5 mm) metal filings, coated with grease, are allowed to float on the surface of a liquid, the sliding discharges will jump between them, travelling 3 - 5 times further. Apparently, the discharges do not pass through the metal particles, but under them, since the filings scatter upwards in all directions from the path at each sliding discharge, with a velocity and strength similar to that of an explosion.

A discharge produced in the vicinity of an object coated with grease or oil cleans it off. The oil is eliminated from the vegetable cells containing it, while grease is eliminated from the animal cells containing it. At the same time, the tissue cells are destroyed, making the extraction of oil more complete.

This method of extracting or removing oily substances may present some practical interest.

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The experimental data indicate that it is possible to use the electrohydraulic effect in synthesis and catalysis, as well as in producing various polymers, emulsions, and colloids, in accelerating chemical reactions, increasing the activity of catalyzers, producing multivalent ions ~~m~~ in branch discharges, and so on.

The diversity of the phenomena which occur in liquids when branch discharges and surface or sliding discharges are produced in them will make it possible to learn more about the nature of liquids, and especially about the structure and

properties of their surface layers. This is shown by the form in nature of the discharges, which always depend only on the composition of the liquid for given conditions of the circuit.